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H03F 1/34

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H3W WVX
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(56) Documents Cited
GB 2293935 A **WO 97/15980 A1**

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INT CL[6] **H03C 1/52 , H03D 7/16 , H03F 1/32 1/34 , H04B 1/04 , H04L 27/36**
ONLINE:WPI

(54) Abstract Title
RF transmitter amplifier with Cartesian feedback and use of test DC offsets to reduce carrier breakthrough

(57) An RF transmitter employs negative feedback to reduce non-linearities in power amplifying means 18 to 21 and, since the transmitter received as input I and Q components, a Cartesian Loop is provided, by means of which a signal derived from the output of the amplifier by a probe 22 is split into de-modulated I and Q components in order to provide feedback signals at 27 and 28. Unfortunately the negative feedback cannot correct for errors in the feedback loop itself, and component imperfections introduce a DC offset into the feedback loop. The modulation is suppressed carrier but the DC offset re-introduces the carrier. The invention provides a method of reducing the DC offset to reduce the carrier breakthrough by injecting known DC offsets into the I and Q inputs and measuring the resulting ripple in the output of the power amplifier means corresponding to the re-introduced carrier, enabling calibration offset DC levels to be calculated and injected into inputs 27, 28.

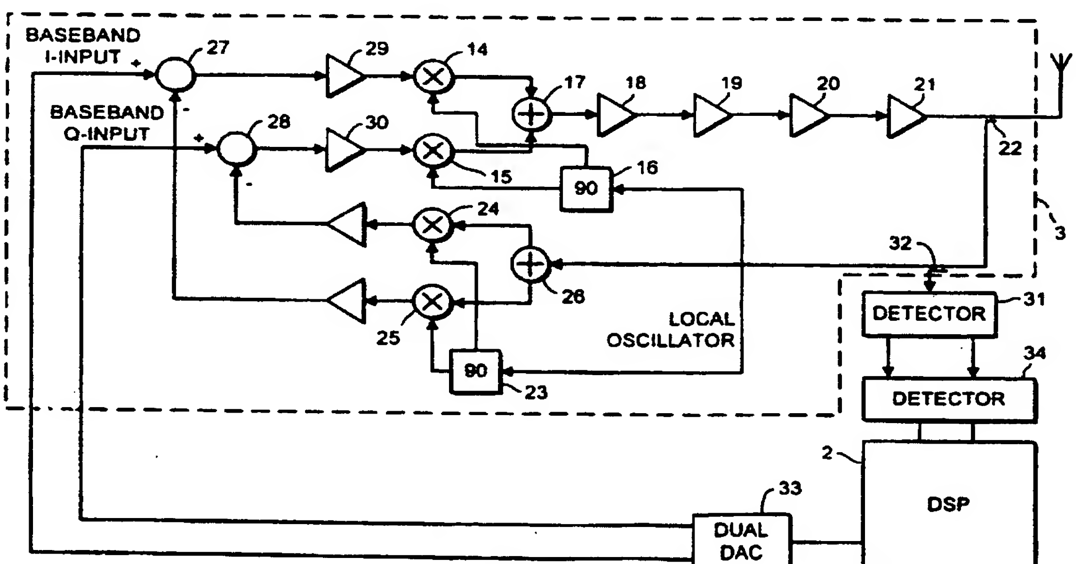

FIG. 3

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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

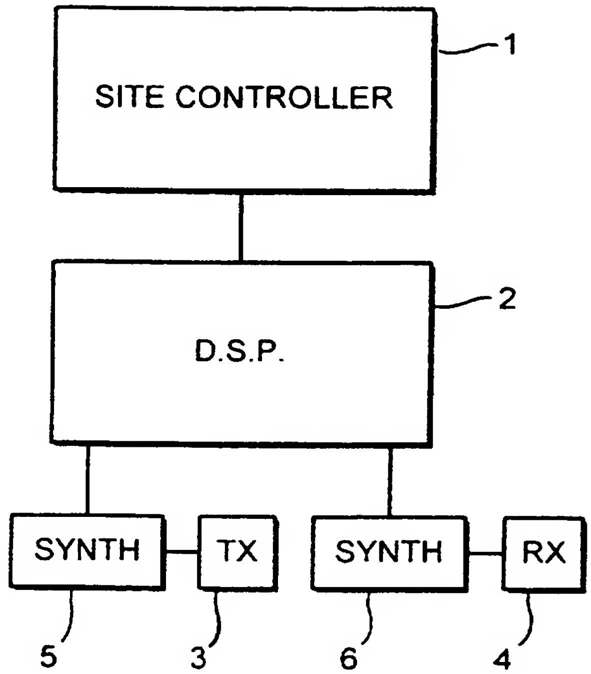
SITE CONTROLLER
1
D.S.P.
2
SYNTH
TX
SYNTH
RX
5
3
6
4

FIG. 1

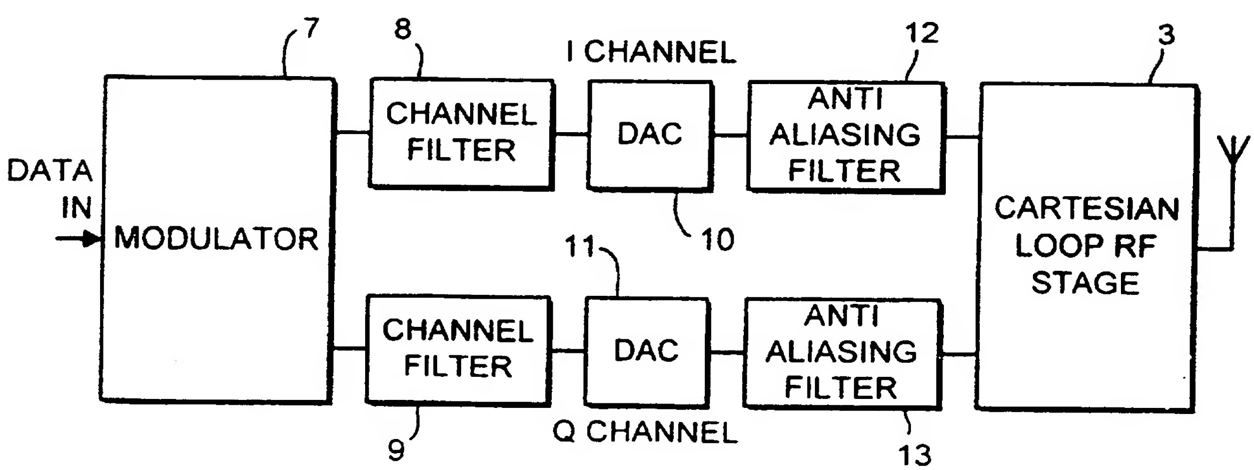
7
8
I CHANNEL
12
3
DATA IN
MODULATOR
CHANNEL FILTER
DAC
ANTI ALIASING FILTER
CARTESIAN LOOP RF STAGE
10
11
CHANNEL FILTER
DAC
ANTI ALIASING FILTER
9
Q CHANNEL
13

FIG. 2

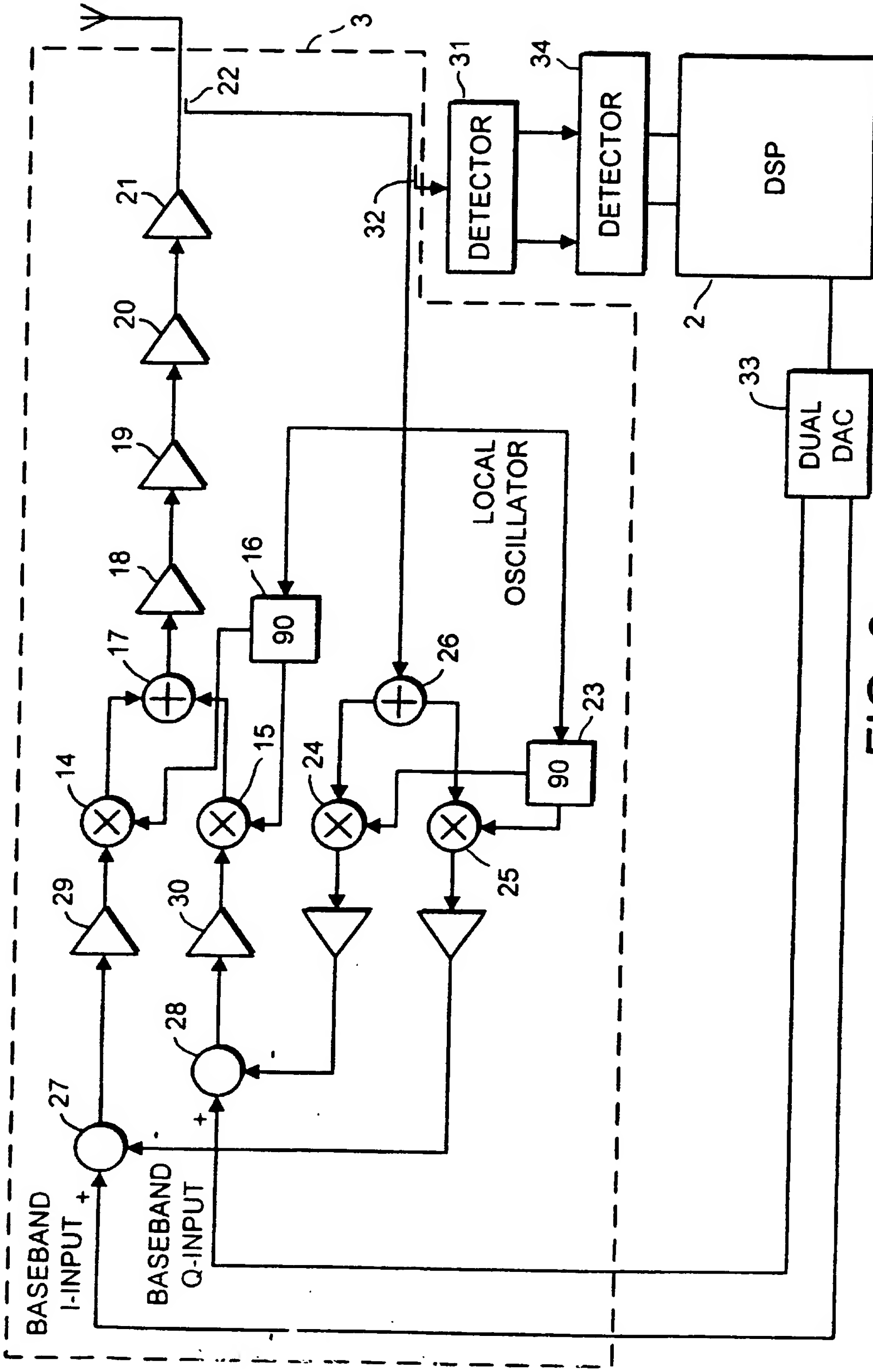
BASEBAND I-INPUT
BASEBAND Q-INPUT
LOCAL OSCILLATOR
DETECTOR
DETECTOR
DSP
DUAL DAC
90
90

FIG. 3

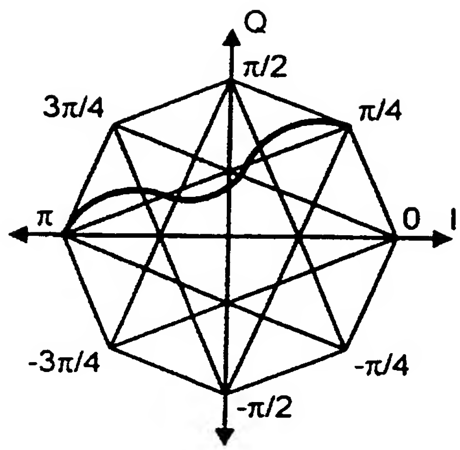

FIG. 4

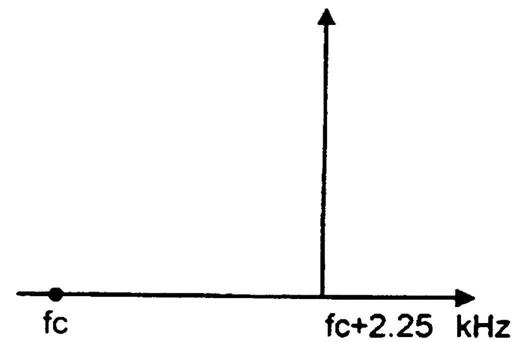

FIG. 5


FIG. 6

FIG. 7

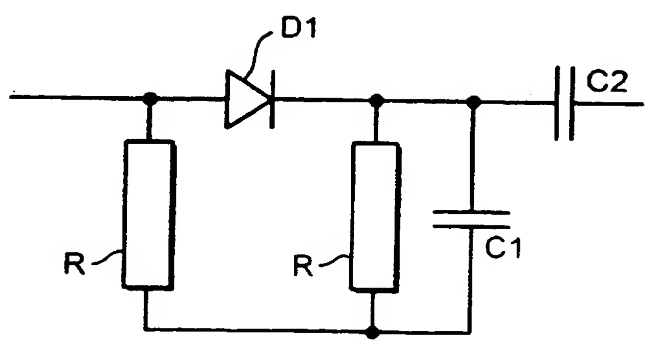

FIG. 8

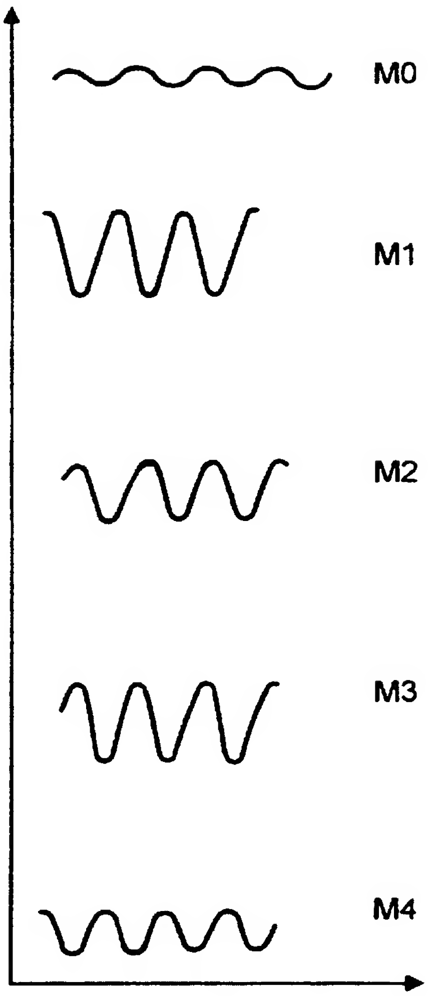

FIG. 9

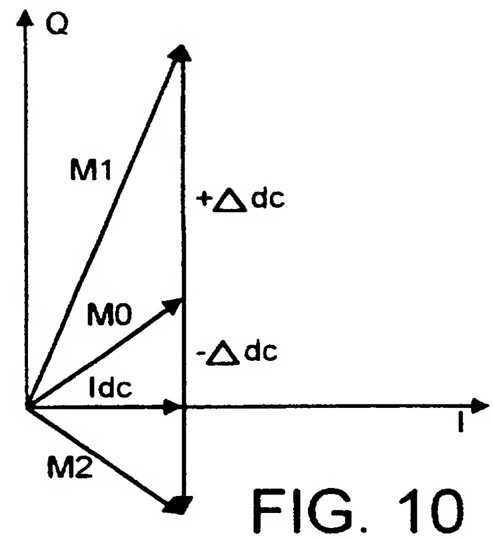

FIG. 10

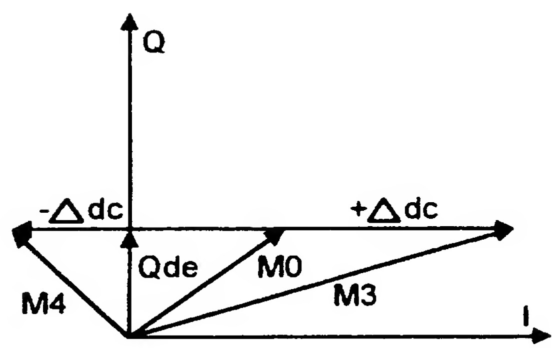

FIG. 11

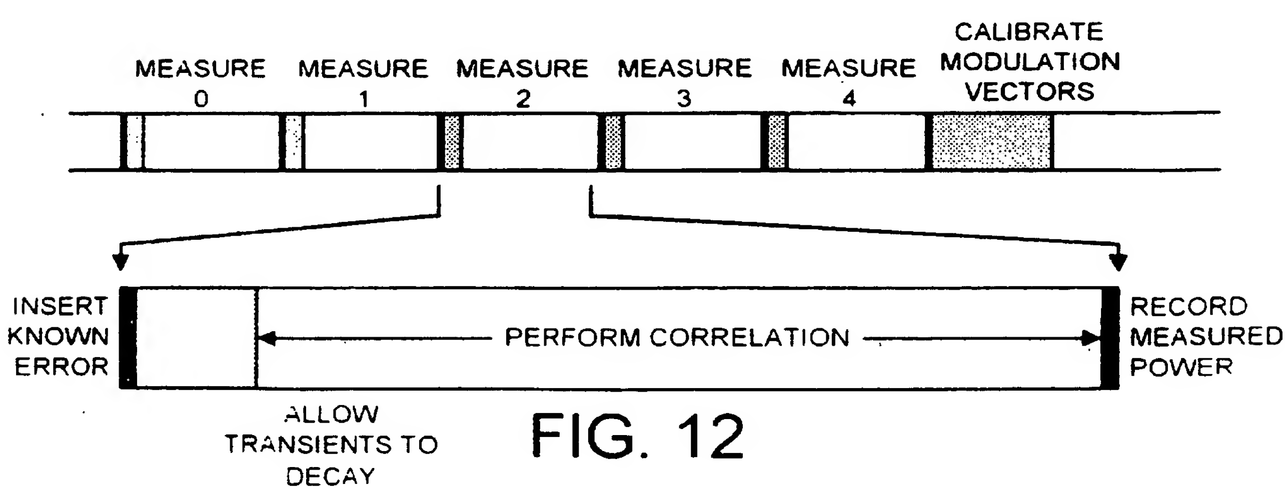

FIG. 12

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RF TRANSMITTER

This invention relates to RF transmitters.

The invention particularly relates to RF transmitters for generating suppressed carrier RF signals from in-phase and quadrature baseband input signals.

To prevent energy being carried over into sidebands which would contravene broadcasting regulations, one technique used is for the transmitter to employ linear power amplifiers.

Accordingly, a feedback loop means is used so that the in-phase and quadrature input signals are compared with signals derived from the output of the power amplifier means, de-modulated using quadrature RF reference signals, to produce respective in-phase and quadrature feedback signals, which are used to produce error signals, and the error signals are modulated onto respective RF quadrature reference signals and combined to produce the suppressed carrier RF signal for input to the power amplifier means such that in the process the feedback is responsible for pre-distorting the input to reduce non-linearities in the power amplifier means.

Unfortunately this can only correct for non-linearities in the power amplifier and modulator means and not for errors in the feedback loop itself. It is found that such errors are actually responsible for introducing DC offsets into the feedback loop which

are then responsible for re-introducing a component of the carrier into the output.

It has been proposed to reduce this DC offset error in an iterative manner by making a series of adjustments to the DC input level of the in-phase and quadrature input signals and maintaining those which were responsible for reducing the amount of re-introduced carrier. However, it was found that this procedure took a relatively long time in order to be effective.

The invention provides an RF transmitter for generating a suppressed carrier RF signal from in-phase and quadrature baseband input signals, comprising power amplifier means, feedback loop means arranged so that the in-phase and quadrature input signals are compared with respective signals demodulated using quadrature RF reference signals from signals derived from the output of the power amplifier means, to produce respective in-phase and quadrature error signals, means for modulating the error signals onto respective quadrature RF reference signals and for combining them to produce a suppressed carrier RF signal for input to the power amplifier means, the input thus being pre-distorted to reduce non-linearities in the power amplifier means, and means for applying a calibration DC component to the in-phase and quadrature input signals based on measurements of signals derived from the output of the power amplifier means when a known DC offset is injected into the in-phase and quadrature input signals, to reduce carrier breakthrough.

The calibration can be performed relatively rapidly, because the pre-distorting DC

component is calculated from the measurements made during a defined period.

The values can be measured by using a detector such as a diode detector to sense a signal derived from the output of the power amplifier means in order to detect the envelope amplitude variation corresponding to the transmitted output, and correlation means or filtering means can be employed to quantify the amount of the amplitude variation which relates to the carrier being re-introduced.

An RF transmitter constructed in accordance with the invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a block diagram of a base station for private mobile radio system, in which base station the transmitter is incorporated;

Figure 2 is a block diagram of the RF transmitter;

Figure 3 is a block diagram of a Cartesian Loop RF Stage of the transmitter;

Figure 4 is a phase diagram showing the possible phase changes of the transmitted carrier;

Figure 5 is a spectral diagram showing the generation of a tone offset with respect to the carrier frequency;

Figure 6 is a vector diagram showing the vectors of the tone illustrated in Figure 5 and a small component at carrier frequency;

Figure 7 is a spectral diagram showing the two vectors shown in Figure 6;

Figure 8 shows the construction of the detector 31 of Figure 3;

Figure 9 illustrates signals M_0, M_1, M_2, M_3, M_4 used to reduce the breakthrough of a component at the carrier frequency;

Figure 10 is a phase diagram illustrating DC offsets applied to the I input of the Cartesian Loop RF Stage;

Figure 11 is a phase diagram illustrating the addition of DC offsets to the Q input of the Cartesian Loop RF Stage; and

Figure 12 illustrates the calibration process.

Referring to Figure 1, the RF transmitter forms part of a base station of a digital private mobile radio network. The network typically consists of base stations, each connected by land lines to switching centres, which interface with the national telephone system. The users of the system employ mobile stations which communicate with their nearest base station. Two mobile stations which are in the range of the same

base station may communicate via that base station. Mobile stations in the range of different base stations may communicate via those base stations and an intermediate switching centre. In addition, mobile stations can, in certain circumstances, communicate with other mobile stations. The system is suited to users such as the emergency services and public transport. The messages are communicated in digital form so that a range of facilities including voice, circuit mode data, short data messages and packet mode services are possible.

Referring to Figure 1, the base station consists of a site controller 1, a digital signal processor (DSP) 2, a transmitter output stage 3 and a receiver 4, together with respective synthesisers 5 and 6. The site controller is the highest level of control within the base station. Its function is to control the supervisory functions of the base station, including establishing, maintaining and terminating connections to the DSP 2, which includes typically carrier processor cards. Each carrier processor card processes signals for transmission and reception at one carrier frequency. A signal received from a mobile station is demodulated in a carrier processor card and decoded at the receiver 4, whereupon it is retransmitted via a carrier processor card and I (in-phase) and Q (quadrature) channels are output from the carrier processor card to the transmitter output stage 3. A separate transmitter is associated with each carrier processor card (only one transmitter is shown), and the respective synthesiser 5 generates the local oscillator. Similarly there will be a separate receiver 4 for each carrier processor card, and a respective synthesiser unit 6.

The transmission is time division multiple access (TDMA), and there are four time slots per carrier so that, for each carrier processor card, four communication channels can be maintained. It is necessary, however, to reserve one communication channel for control purposes.

The modulation performed in the DSP 2 of Figure 1 is differential quadrature phase shift keying (DQPSK). What this means is that, for each consecutive pair of input data bits (each dibit) to the modulator 7 of Figure 2, a change is made in the phase of the transmitted carrier. Referring to Figure 4, which represents in simplified form the possible phases of the transmitted carrier, the phase can be only one of the eight phase angles shown ie. 0, $\pm\ \pi/4$, $\pm\ \pi/2$, $\pm\ 3\pi/4$, π. Further, each dibit can change the transmitted carrier only by $\pm\ \pi/4$, or $\pm\ 3\pi/4$. The actual modulation of the I and Q channels onto the carrier takes place in the Cartesian Loop RF Stage (the transmitter output stage). Each dibit input into the modulator 7 produces an output on each of the I and Q channels. If the position was (which it is not) that the I and Q channels maintained a constant phase, it can be visualised how successive dibits could produce, say, on the I channels, successive digital values as to represent a sinusoid and, on the Q channel similar values but 90° out of phase. In fact, the modulation is differential phase shift keying, which means that changes in phase of the transmitted carrier represent the information bits. For example, if the input to the modulator consisted of successive pairs of dibits each representing 1,1, the values output by the modulator 7 on each channel corresponding to each input digit could be responsible for advancing the phase of the I and the Q channel each by 45°. This would be equivalent to

advancing by 45° along the sequence of digital values representing a sinusoid referred to above. Because the filtering which takes place in the I and Q channels, the phase changes linearly with time rather than moving in steps. Thus in reality each straight line in Figure 4 would actually be curved: one curved line is shown as an example. This linear phase change is manifested in a frequency shift from the original unmodulated carrier frequency f_c. The frequency offset is proportional to the bit rate of the incoming data string. The gross data rate in the DSP 2 is 36k bits per second, which gives a rate for the dibits of 18k symbols per second. Since eight $\pi/4$ transitions represents one cycle, the symbol rate results in a shift of the carrier frequency of 2.25kHz.

Referring to Figure 2, the samples being output from the modulator 7 are I and Q baseband samples and these are fed into channel filters 8, 9 which are root raised cosine filters implemented using a linear phase digital Finite Impulse Response (FIR) filter. The digital samples are then converted into analogue signals by means of two 12 bit DACs 10, 11 for the I and Q channels. The analogue signals are then fed into anti-aliasing filters 12, 13 to remove the sampling frequency component of 144kHz and fed into the Cartesian Loop RF Stage 3.

The circuit elements 7-13 may be provided by dedicated hardware, but are more conveniently carried out by the DSP 2.

The analogue signals entering the Cartesian Loop RF Stage on the I and Q channels are

baseband signals, and are modulated on to a carrier in the Cartesian Loop RF Stage, described in more detail now with reference to Figure 3. The modulation is double sideband, suppressed carrier (DSB-SC). The I channel is modulated by an in-phase local oscillator via mixer 14, and the Q channel is modulated by a quadrature local oscillator via mixer 15. Quadrature phase shift device 16 produces the signals from an input from the local oscillator from synthesiser 5 (Figure 1) operating at carrier frequency (in this case 396.5MHz). The I and Q signals thus modulated onto quadrature carriers are then combined at adder 17 and a DSB-SC waveform results. Figure 5 shows the spectrum of the transmitted signal, and it will be noted that no component is shown at the carrier frequency f_c.

The Cartesian Loop RF Stage includes a 25W class AB power amplifier illustrated by linear amplifiers 18 to 21 in cascade.

It is necessary to correct for non-linearities in the amplifier chain 18-21, and this is done by means of the (negative feedback) Cartesian Loop.

A probe 22 picks off a part of the output signal and feeds it back to the input I and Q channels. Of course, the signal picked off is modulated and so must be demodulated, again using quadrature signals derived from the same local oscillator by means of quadrature phase shift device 23 and mixers 24 and 25 which act on part of the feedback signal which is split at splitter 26. The demodulated I and Q channels are fed back to nodes 27 and 28, where the feedback signals are subtracted from the input

signals. If there is sufficient gain around the loop, the feedback signal will strive to track closely the input signal, so that the signal leaving the nodes 27 and 28 and being fed to the frequency changes 14 to 17 are error signals and the input to the amplifiers 29 and 30 behave as virtual earths.

It will thus be seen that the Cartesian Loop is a closed loop system where a part of the transmitted signal is fed back and compared with the input to produce an error signal. The error signal is then used to pre-distort the input to the power amplifier so that a linear response is achieved.

The Cartesian Loop only cancels out distortions if the feedback loop is perfect. Unfortunately, this is not the case, and in fact both the splitter 26 and the mixers 24, 25 introduce a small DC offset into the signal picked off from the RF output 22. The DC offset is responsible for introducing into the transmitted output a small component at the carrier frequency f_c (Figure 7), since the local oscillator mixed with DC produces the carrier.

The result of this so-called carrier breakthrough can be considered by reference to Figure 5, 6 and 7. It will be remembered that the large vector in Figure 7 is the tone generated at the frequency offset by 2.25kHz from the carrier. The small vector is the re-introduced carrier component. The carrier component is therefore modulated by a much larger component at 2.25kHz. It is easier to visualise this by referring the modulation to the tone, in which case the carrier modulates this tone at 2.25kHz. The

tone is thus amplitude modulated at 2.25kHz.

Detector 31 picks off the feedback signal using probe 32 and detects the envelope amplitude of the signal. The detector 31 may be configured like the diode detector shown in Figure 8. The resistor R2 and capacitor C1 provide the necessary time constant to detect amplitude variations in the envelope of the amplitude modulated (AM) wave.

The carrier breakthrough causes a ripple at 2.25kHz, and a correlation is performed by means not shown to detect the amplitude of that ripple.

The ripple detected is a combination of the I and Q channels, and may be represented by a vector M_0 at 2.25kHz. In order to achieve cancellation of the DC offset introduced in the negative feedback path, it is necessary to calculate this vector M_0.

The vector M_0 has been illustrated in Figures 10 and 11 and is a complex quantity. The correlations at 2.25kHz are performed using quadrature waveforms to detect the I and Q components of vector M_0. The vectors I_{dc} and Q_{dc} must be calculated in order to cancel the DC offset which brings vector M_0 into existence. They cannot be worked out from a knowledge of M_0 alone, since they appear at different parts of the circuit and the relation between them is not known.

The Applicants have previously attempted to reduce the vector M_0 in an iterative

manner, by making changes of the DC level in the feedback path and then noting whether M_0 was increased or reduced. Nevertheless, this is a very time-consuming process.

In accordance with the invention, a calculation is made after five measurements in order to obtain a measure of the ripple vector M_0. In each of five time slots, an initial period is allowed to elapse before measurements are made to allow transients to decay. Then the correlation is performed with quadrature 2.25kHz waveforms. In the first measurement period the I and Q components of vector M_0 are calculated. In the second measurement period ("Measure 1") a positive offset current is generated by DAC 33 and injected into the I input at node 27, and the ripple is measured to calculate vector M_1. In the next measurement period ("Measure 2") a negative offset of the same value is generated by DAC 33 and is subtracted from the I channel, and the corresponding vector M_2 is measured. Since the positive DC current offset (+ Δ_{dc}) and the negative DC current offset (- Δ_{dc}) can be plotted on the vector diagram 10 and are applied at the same point in the circuit at which the error I_{dc} is to be cancelled, the unknown quantity I_{dc} can now be calculated.

In the next measurement slot ("Measure 3"), a positive offset current is added to the Q channel at node 28 by means of DAC 33 and vector M_3 representing the 2.25kHz component is measured, and in the final measuring period ("Measure 4") a negative

DC offset current is added to node 28 by means of DAC 33, and the ripple M_4 is measured. In the same way, it is then possible to calculate Q_{dc}.

The calculation of I_{dc} and Q_{dc} is performed after "Measure 4" in the DSP 2.

DSP can now, via DAC 33 inject I_{dc} and Q_{dc} current offsets into respective nodes 27, 28, and it is found that this will reduce the 2.25kHz carrier breakthrough component significantly. It does not reduce it all in one go, and, but this can be reduced to a low level in a matter of three of four such adjustments.

Of course the correction is advantageously performed on a continuous basis. The telecommunication time slots last 14.2 μs, and the whole measurement and calculation process illustrated in Figure 12 can take place in one time slot.

It will be appreciated that the injected currents $\pm\ \Delta_{dc}$ are such as to increase and decrease the DC level at the corresponding node ie. it could be that after injection of $+\ \Delta_{dc}$, the DC level moves from one negative level to another, less negative DC level.

The correlation process is performed in DSP 2 and, to this end, an ADC 34 is provided.

Of course variations may be made without departing from the scope of the invention. Thus, the invention is not restricted to base stations of private mobile radio networks, and is also applicable to transmitters with Cartesian Loops in switching centres, or to transmitters with Cartesian Loops used in base stations or switching centres of other mobile radio systems or, indeed, more generally to any RF transmitter employing a Cartesian Loop.

CLAIMS

1. An RF transmitter for generating a suppressed carrier RF signal from in-phase and quadrature baseband input signals, comprising power amplifier means, feedback loop means arranged so that the in-phase and quadrature input signals are compared with respective signals demodulated using quadrature RF reference signals from signals derived from the output of the power amplifier means, to produce respective in-phase and quadrature error signals, means for modulating the error signals onto respective quadrature RF reference signals and for combining them to produce a suppressed carrier RF signal for input to the power amplifier means, the input thus being pre-distorted to reduce non-linearities in the power amplifier means, and means for applying a calibration DC component to the in-phase and quadrature input signals based on measurements of signals derived from the output of the power amplifier means when a known DC offset is injected into the in-phase and quadrature input signals, to reduce carrier breakthrough.

2. An RF transmitter as claimed in Claim 1, including means for applying a known increase and a known decrease to the DC level of each of the in-phase and the quadrature signals.

3. An RF transmitter as claimed in Claim 1 or Claim 2, in which the means for applying a calibration DC component is arranged to base the values on measurements when the known DC offset is injected as well as when no DC offset is being injected.

4. An RF transmitter as claimed in any one of claims 1 to 3, including detector means for measuring the envelope amplitude of a signal derived from the output of the power amplifier means.

5. An RF transmitter as claimed in Claim 4, including correlation means to measure the amount of envelope amplitude modulation corresponding to the non-suppressed carrier.

6. An RF transmitter substantially as herein described with reference to and as shown in the accompanying drawings.

7. A base station of a mobile radio system which includes an RF transmitter as claimed in any one of claims 1 to 6.

8. A private mobile radio network employing a base station as claimed in Claim 7.

9. A method of reducing carrier breakthrough in an RF transmitter for generating a suppressed carrier RF signal from in-phase and quadrature baseband input signals, comprising the steps of comparing the in-phase and quadrature baseband signals with respective signals demodulated using quadrature RF reference signals from signals derived from the output of power amplifier means, to produce respective in-phase and quadrature error signals, modulating the error signals onto respective quadrature RF

reference signals and combining them to produce a suppressed carrier RF signal input to the power amplifier means, the input thus being pre-distorted to reduce non-linearities in the power amplifier means, and applying a calibration DC component to the in-phase and quadrature input signals based on measurements of signals derived from the output of the power amplifier means when a known DC offset is injected into the in-phase and quadrature input signals, to reduce carrier breakthrough.

10. A method as claimed in Claim 9, which includes the steps of injecting known DC offsets into the in-phase and quadrature input signals, and measuring signals derived from the output of the power amplifier means both when the offsets are injected and when no offsets are injected, and calculating the calibration DC component required to be applied to the in-phase and quadrature input signals to reduce carrier breakthrough.

11. A method of reducing carrier breakthrough in an RF transmitter for generating a suppressed carrier RF signal substantially as herein described with reference to the accompanying drawings.

The Patent Office

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Application No:	GB 9719224.9	**Examiner:**	D. Midgley
Claims searched:	1-11	**Date of search:**	6 February 1998

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.P): H3W WUV, WUL,WVT,WVX

Int Cl (Ed.6): H03C 1/52 H03D 7/16 H03F 1/32 1/34 H04B 1/04 H04L 27/36

Other: ONLINE:WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	GB2293935 A (LINEAR)	1,9
A	WO 97/15980 A1 (PHILIPS)	"

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.